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Determining Benefits and Costs of Improved Water Heater Efficiencies

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ABSTRACT

Economic impacts on individual consumers from possible revisions to U.S. residential water heater energy-efficiency standards are examined using a life-cycle cost (LCC) analysis. LCC is the consumer's cost of purchasing and installing a water heater and operating it over its lifetime. This approach makes it possible to evaluate the economic impacts on individual consumers from the revised standards. The methodology allows an examination of groups of the population which benefit or lose from suggested efficiency standards. The results show that the economic benefits to consumers are significant. At the efficiency level examined in this paper, 35% of households with electric water heaters experience LCC savings, with an average savings of $106, while 4% show LCC losses, with an average loss of $40 compared to a pre-standard LCC average of $2,565. The remainder of the population (61%) are largely unaffected.

PROBLEM

Policy decisions involve assessments of benefits and costs. However, questions such as what level of benefit is significant and at what point do costs become important are not universally agreed upon. A method to determine the benefits and costs of one type of policy decision and ways to interpret the results of the analysis are discussed in this paper.

This benefit and cost study grows out of work done for the U.S. Department of Energy (DOE).[1] Federal law sets energy conservation standards for various consumer products and directs DOE to create or amend energy standards for major household appliances. Any new or amended standard must achieve the maximum improvement in energy efficiency that is technologically feasible and economically justified. This study presents the overall approach used in the LCC analysis and illustrates it with results for electric water heaters.

APPROACH: DETERMINING CONSUMER BENEFITS AND COSTS

Economic impacts on individual consumers from possible revisions to U.S. residential water heater energy-efficiency standards are examined using a life-cycle cost (LCC) analysis. LCC is the total cost a consumer pays during the lifetime of a water heater, including purchase price and operating expenses (which cover energy expenditures and any maintenance costs). Future operating expenses are discounted to the time of purchase and summed over the water heater's lifetime. The effect of standards is a change in the operating expense (usually decreased) and a change in the purchase price (usually increased). The net effect is analyzed by calculating the change in LCC as compared to the base case. Inputs to the LCC calculation include the installed consumer cost (purchase price plus installation cost), operating expenses (energy and maintenance costs), lifetime of the appliance, and a discount rate.

LCC is defined by the following equation:

$$LCC = EquipCost + NPV(D_{rate}, OprCost_{year}, Lifetime)$$

EquipCost (Equipment Cost) is the cost ($) of buying and installing a water heater. This includes the cost of the water heater plus sales tax, installation charges, and, if the water heater is being replaced, charges to remove the old water heater.

NPV (Net Present Value ($)) is the present value of a future stream of expenditures or earnings and is defined by the following equation:

$$NPV = \sum_{year=1}^{Lifetime} \frac{OprCost_{year}}{(1 + D_{rate})^{year}}$$

D_{rate} (Discount rate (%)) is defined as the rate at which future expenditures are discounted to establish their present value. For this study, it is the consumer's interest rate minus inflation.

OprCost (Operating Cost) is defined as the annual expense to keep a water heater operating. It has two parts: fuel and maintenance. Fuel costs are calculated by multiplying annual water heater energy use by the energy price paid by the household. Maintenance costs are repair charges or the cost of a service contract.

Lifetime is the length of time the water heater will provide service.

At this point, the benefits and costs to the consumers can be defined as net changes in LCC when comparing various design options to the baseline:

$)LCC = LCC_{base} - LCC_{design}$

where LCC_{base} refers to a typical future water heater in the absence of new efficiency standards and LCC_{design} is a future higher efficiency unit, given standards.

If)LCC is less than 0, then there is a net cost to the consumer and if it is greater than 0, it indicates a benefit (net savings) to the consumer. Using this calculation, it is possible to determine the fractions of the population that benefit or are disadvantaged by efficiency standards.

Baseline and Design Options

The overall analysis considers various water heater models: an "existing baseline," representing water heaters in use in 1998; a "2003 baseline" design, anticipated to be the standard design in 2003 absent new efficiency standards; and various "design options", representing efficiency improvements to meet possible energy-efficiency standards. The water heaters considered are fueled by electricity, gas, or oil. Most water heater manufacturers currently use HCFC-141b as a blowing agent for the insulation, which damages the ozone layer and will be phased out by January 1, 2003. Consequently, the 2003 baseline and design options use either HFC-245fa or water-blown insulation, the two current leading candidates to replace HCFC-141b.

Key Input Variables

The major input variables used in the water heater LCC analysis are energy price, discount rate, retail price, installation cost, household characteristics, and water heater lifetime. All of these variables are expressed as distributions, which represent a range of reported or expected values. Several distribution types are used in this analysis. Triangular distributions are used when minimum, most-likely, and maximum values are available. When only a mean and variance about a random variable are known, a normal distribution is used to describe the variable. Custom distributions are used when series of actual data was known. When only minimum and maximum are known, uniform distribution was used.

Some of the variables are obtained from DOE's Energy Information Administration (EIA) *Residential Energy Consumption Survey* (RECS) for 1993, which contains data from a representative sample of U.S. residential households.[2] Price trends from EIA's *Annual Energy Outlook 1999* (AEO99) were used to scale the distribution of marginal energy prices for future years.[3]

Marginal Energy Prices. Marginal energy prices are those prices consumers pay (or save) for the last unit of energy used (or saved). Consumer marginal electricity prices for this analysis were estimated directly from household data in the 1993 RECS public use data survey as the change in household monthly energy bill divided by the change in monthly energy consumption. This provides a marginal energy price rate based on actual household bills. LBNL calculated the slope of the regression line for four summer months (June-September) and, separately, for the eight winter (October-May) months. The annual marginal price is the weighted average of the two seasonal prices, where the weighting used the relative energy consumption in each season. For water heaters, the weighting was 28% summer and 72% winter.[4]

Future Energy Prices. Future electricity costs will vary from house to house. Two primary factors contribute to this variation. One is the existing variability in energy prices, which depend on the rate schedule of the local utility and the consumption pattern of the particular household. The other is the uncertainty of future energy prices, which is further complicated by the current restructuring of the electric supply industry.

Given the uncertainty of projections of future energy prices, the LCC analysis used a scenario approach to examine the robustness of proposed energy-efficiency standards under different energy price conditions. The AEO99 Reference Case provides the base scenario. For the high and low energy price scenarios, other scenarios from AEO99 were used.

Discount Rate. A distribution of discount rates represents the variability in financing methods consumers use in purchasing appliances. The method of purchase (e.g., cash, credit card) is assumed to indicate the source of funds and type of financing used by consumers. Consumers purchase water heaters separately or as part of new homes. Purchases through retail vendors may be paid by cash, credit cards, or retailer loans. Whirlpool Corporation indicated that approximately 40% of "white goods" are purchased in cash, 35% with credit cards, and 25% with retailer loans.[5] Purchases of water heaters for new homes are currently about 20% of shipments.

Household Characteristics. The RECS data provided a sample of 7,111 households from the population of all primary, occupied residential housing units in the U.S. Of these, 2,323 household records were used in the analysis. This sample is assumed to represent 30,279,600 actual households. An additional 2,899 households having non-electric water heaters were analyzed in a parallel study, reported elsewhere.

The household records included in this analysis have the following defining features: an individual electric water heater; an indication of water heater tank size; and sufficient utility billing data. Household characteristics, such as number of people, presence of appliances, water temperature, and energy prices, are used to determine energy consumption and cost.

Lifetime. *Appliance Magazine* reports a range of 4-19 years for electric water heaters and a most likely value of 12 years.[6] In this study, this is interpreted as a triangular distribution.

Uncertainty and Variability

To account for uncertainty and variability, the LCC model was developed using Microsoft Excel combined with Crystal Ball. Crystal Ball is commercially available software that provides risk analysis capabilities. The model uses a Monte Carlo simulation to account for uncertainty and variability of input values. The model accepts ranges (distributions of values) as input for each variable and performs the calculations thousands of times to determine a distribution of the outputs. This distribution reflects the probability of the values that would occur.

When making observations of past events or speculating about the future, imperfect knowledge—uncertainty—is the rule rather than the exception. For example, the energy actually consumed by a water heater has seldom been directly recorded. Rather, energy consumption is usually estimated based upon available information. Even direct laboratory measurements have some margin of error. When estimating numerical values expected for quantities at some future date, the exact outcome is rarely known in advance.

Variability means that different applications or situations produce different numerical values for a quantity. Specifying a value for a quantity may be made even more difficult if the value depends on a number of other factors. For example, the amount of hot water used per day by a household depends on the household characteristics (e.g., number of persons, presence of dish- or clothes-washer, etc.). Surveys can be helpful here, and analysis of surveys can relate the variable of interest (e.g., gallons of hot water use per day) to other variables that are better known or easier to forecast (e.g., number of persons).

LCC Modules

The LCC analysis uses a spreadsheet-based calculation methodology. A weighted random selection of RECS households is sampled 10,000 times.

The spreadsheet contains five modules, each calculating a different input of the LCC. The Draw Module calculates the amount of hot water used by each household. The second module, Energy Analysis, calculates how much energy is used in each household analyzed in the Draw Module and evaluates efficiency alternatives—the 2003 baseline and all the design options—for each household sampled. The third module, Operating Cost, calculates the annual operating cost for each household, for the 2003 baseline water heater and all the design options, using projected future energy prices. The fourth module, Equipment Cost, calculates each consumer's cost to purchase and install a water heater. This calculation uses manufacturers' costs, with adjustments for the water heater sizes and retail markups. The final step in the analysis, the LCC module, determines the life-cycle cost and payback for each water heater design option for each sampled household.

RESULTS

To evaluate the economic impact on consumers, an LCC analysis is conducted for each of six design options chosen for analysis. This includes an estimation of the percent of the population that would realize reduced LCC from each design option.

The results for electric water heaters with HFC-245fa-based insulation are presented in Table 1 and Figure 1. Table 1 lists the portion of the population that has any savings or costs, in terms of life-cycle cost, from each energy-efficiency design option. For each design option, the table shows the average and maximum possible savings for that fraction of the population benefitting; it also shows the average and maximum costs for the disadvantaged fraction of the population. The middle row lists the percent of the population encountering insignificant (up to 2%) savings or cost.

Figure 1 presents a summary of the life-cycle cost information by percent of the population experiencing net savings or costs. Each bar refers to a specific design option. The bar's height above the zero horizontal axis shows the percentage of households that have a life-cycle savings. Conversely, the portion of the bar below the 0 % horizontal axis show the percentage of households that have a life-cycle net cost. The bars show a greater fraction of the population having net savings except for the last two designs. As the design options increase in energy efficiency and cost, the energy savings are not sufficient to offset the higher initial costs and the net effect is a reduction in the percent of households benefitting. The positive and negative portions of the bars are shaded to show three ranges: significant savings, significant costs, and no significant change. The average baseline life-cycle cost is included as a reference point to indicate the magnitude of the estimated savings or costs.

DISCUSSION OF RESULTS

Table 1 and Figure 1 show the overall distribution of LCC net costs and savings for electric water heaters with different design characteristics. Table 2 summarizes, in terms of net costs/savings, the affect on consumers of the “2.5-inch Insulation” design option. It shows the percent of the total population which would experience net costs (26.1%) and those with savings (73.9%) and compares them to the percent who will experience net costs/savings larger than 2% (3.8%) of the average baseline LCC ($2,565). The values in parentheses indicate the actual dollar amounts of the thresholds.

For this design option, the analysis predicts that 26% of consumers would experience some net cost with the more efficient water heater. However, it is reasonable to assume that there are LCC costs or savings so small that consumers would be unable to distinguish them in their annual expenses. Plus or minus 2% of average baseline LCC is chosen as the band of no consumer impact. Removing this segment of the population makes it possible to clearly show the *significant* net savings and net costs associated with any design option. This also allows for a more informed weighting of benefits and burdens on consumers.

Table 1. Percent of Population Having Net Savings or Costs for Electric Water Heaters

Population		Heat Traps	Tank Bottom Insulation	2-Inch Insulation	2.5-Inch Insulation	Plastic Tank	3-Inch Insulation
Significant Savings	% of sample	14%	21%	30%	35%	21%	15%
	Avg Savings	$73	$79	$94	$106	$111	$119
	Max Savings	$247	$262	$403	$565	$538	$619
Insignificant Savings or Cost	% of sample	86%	79%	69%	61%	57%	38%
Significant Cost	% of sample	0.03%	0.02%	1%	4%	22%	48%
	Avg Cost	$58	$71	$63	$74	$91	$150
	Max Cost	$69	$81	$111	$155	$265	$478
Total (100%)	Avg Savings	$27	$32	$36	$40	$1	-$55

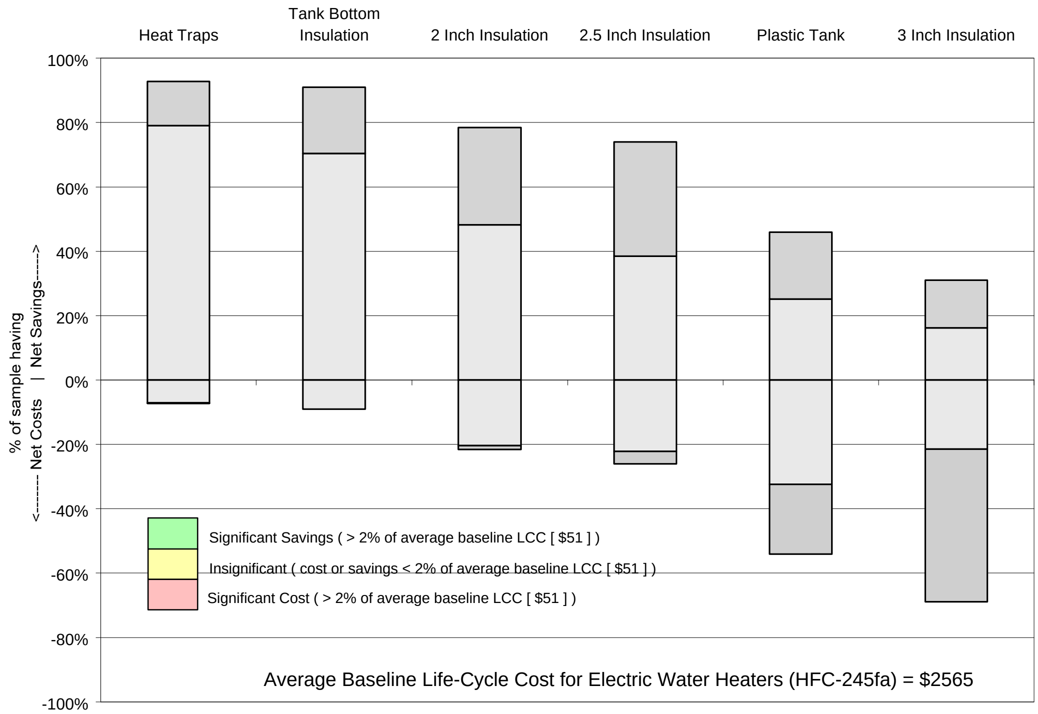

Figure 1 Percent of Sample With Net Savings or Costs for Electric Water Heaters

Table 2.   Percent of Population Having Net Cost/Saving

	$ 2% ($51)	$ 0% ($0)
Net Cost	3.8%	26.1%s
Net Savings	35.4%	73.9%

To illustrate the ±2% assumption, consider the average baseline LCC for electric water heaters of $2,565; 2% of average baseline LCC equals $51. Over the average life of 12 years for an electric water heater, this amounts to less than $4.50 per year. Obviously, this is such a small amount in terms of yearly expenditures that it will not impact consumers' pocketbooks nor their purchase decisions about water heaters. This leaves, therefore, only 3.8% of consumers, who will sustain any significant net costs in the case of the "2.5-inch Insulation" design option.

The results for the majority of the design options show that a very small portion of the population will experience a significant cost. The exceptions are the "Plastic Tank" and the "3-inch Insulation", for which 54% and 69%, respectively, would have net cost.

CONCLUSIONS

This LCC analytic approach makes it possible to evaluate the economic impacts on individual consumers of revised U.S. residential water heater energy-efficiency standards. The method permits an examination of groups of the population to determine how many may experience net savings (or costs) from possible efficiency standards.

The sample shows that the economic benefits to consumers are significant. For the design option considered above, the average LCC savings for 61% of consumers with electric water heaters is $106 and just 4% of households experience a cost averaging $74. The results for gas-fired water heaters, which are not discussed in this paper, show a similar magnitude of savings. In many cases, the benefits to the society in energy savings greatly outweigh the encountered costs.

Based on this analysis, the Department of Energy has chosen the "2.5- inch Insulation" design option for the proposed rule for new efficiency standards for electric water heaters.[7]

FURTHER WORK

LBNL plans to develop a general method for assessing impacts of residential appliance standards on different population segments. This effort will involve identifying data sources containing disaggregated information about household energy consumption, and developing an analytical method for quantifying impacts on relevant subpopulations applicable to any product. The data sources include government and private surveys and other relevant sources. Methods will be developed for better estimating the variation among consumers in energy consumption for specific products (e.g., clothes washers, water heaters, central air conditioners), depending on such factors as climate, demographics differences in usage behavior, and energy prices.

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